Reinstating Floyd-Steinberg: Improved Metrics for Quality Assessment of Error Diffusion Algorithms

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ICISP’08 – Cherbourg-Octeville, France

Introduction

- Halftoning is the process of converting a continuous tone image into another image with a reduced number of tones.

Ordered dithering

- Tiles a dither matrix (*eg*. Bayer, void-and-cluster) for use as threshold values.
- Average quality, fast, parallelisable.

Error diffusion

- Uses feedback through an error diffusion matrix (eg. Floyd-Steinberg, Stucki, JaJuNi...).
- Good quality, hardly parallelisable.

Direct binary search

- Uses a human visual system model to simulate eye behaviour and minimise a global distance.
- Excellent quality, yet very slow (iterative).

What is "quality"?

- One possible metric:

$$E(h,b) = \frac{(||v * h_{i,j} - v * b_{i,j}||_2)^2}{wh}$$

  - *h*: original image
  - *b*: dithered image
  - *v*: human visual system filter
- Smaller error = higher quality

The human visual system model

Relative quality of algorithms

- Using *lena.tga* and a Gaussian HVS:
  - 8×8 Bayer dithering:

    $$E = 0.06352$$

  - Floyd-Steinberg dithering:

    $$E = 0.01847$$

  - Direct binary search:

    $$E = 0.00984$$

- Other images show a similar trend

Image displacement

- Floyd-Steinberg kernel: $\frac{1}{16}\begin{vmatrix} - & x & 7 \\ 3 & 5 & 1 \end{vmatrix}$
- Error is propagated to the right and bottom, which shows in the image:

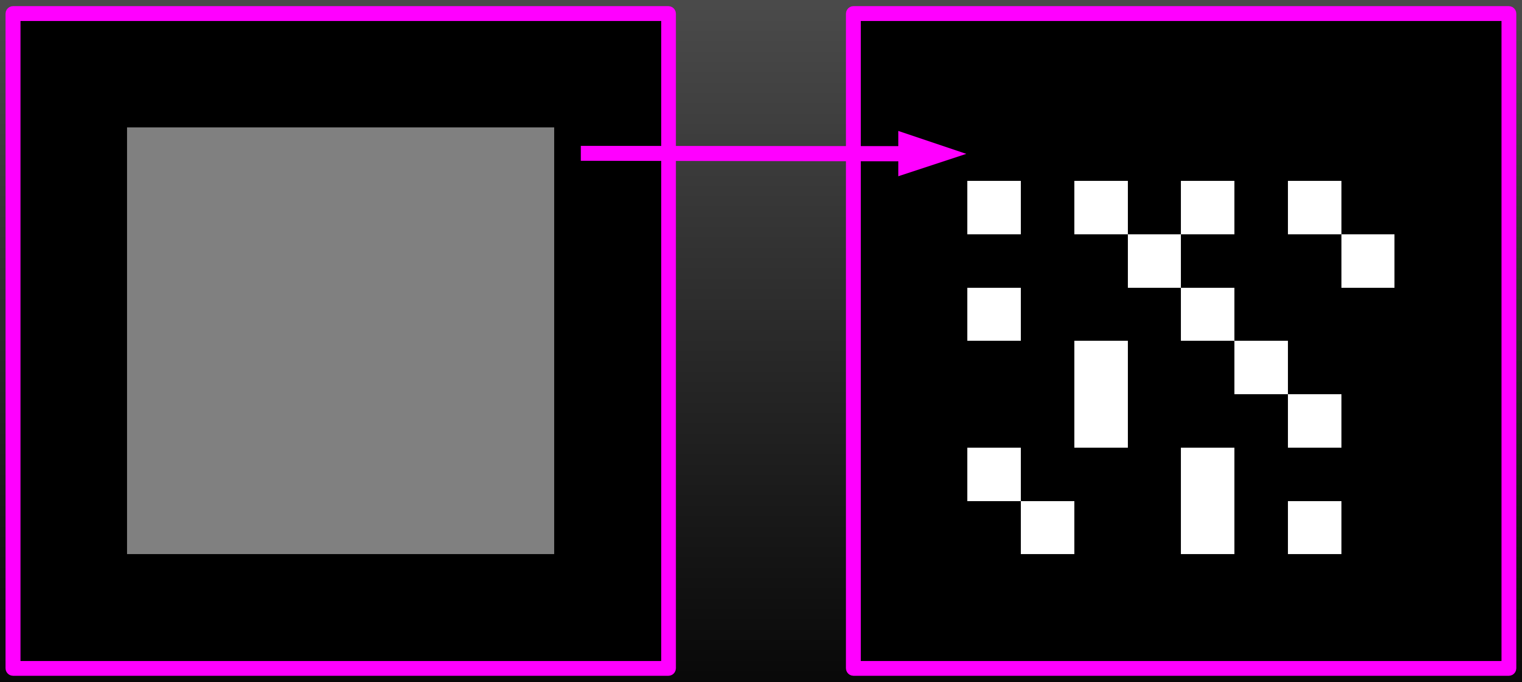


Image displacement

- Slight formula modification:

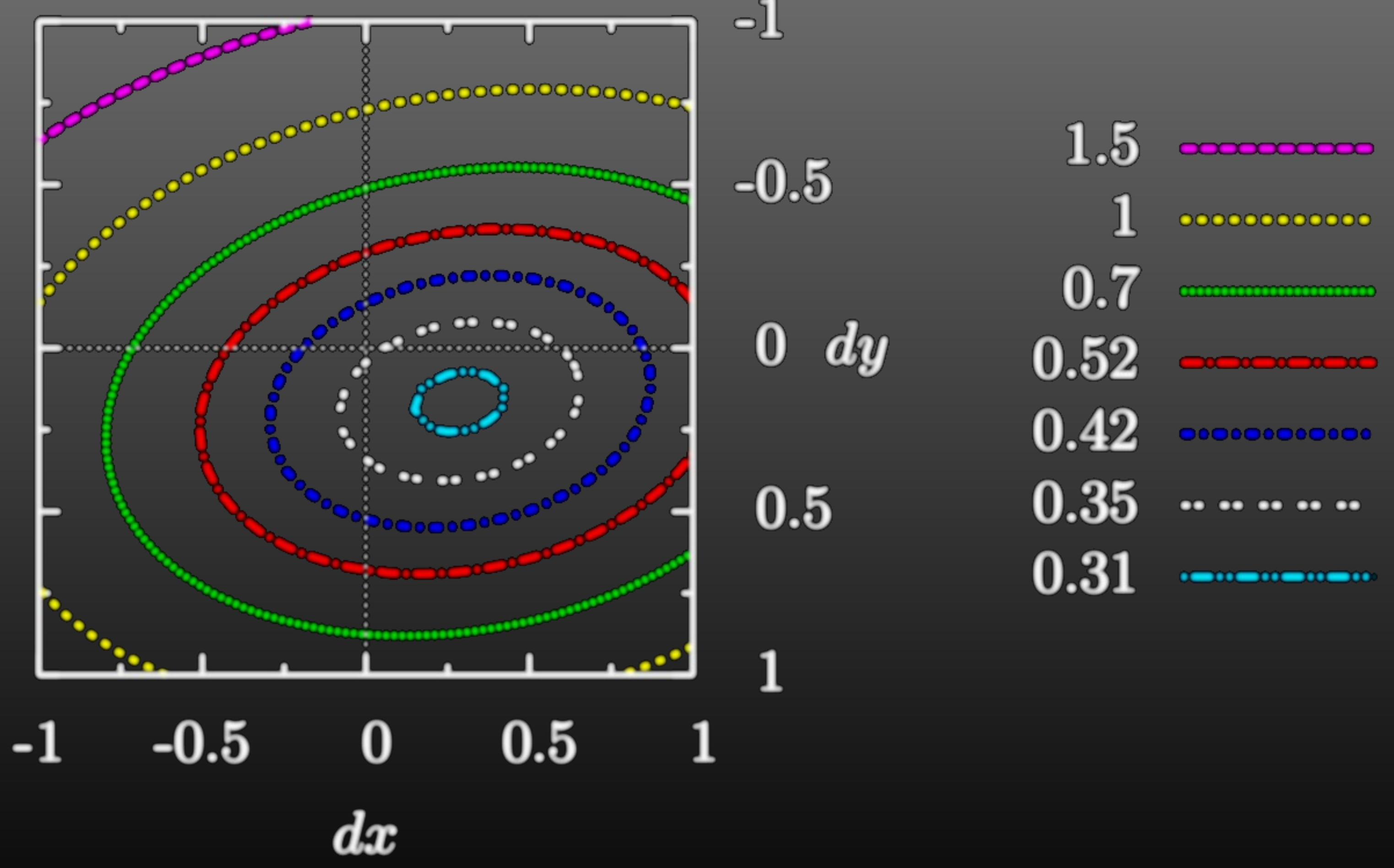
$$E_{dx,dy}(h,b) = \frac{(||v * h_{i,j} - v * t_{dx,dy} * b_{i,j}||_2)^2}{wh}$$

  - $t_{dx,dy}$ translates the image by (dx,dy)

- For most error-diffused images, $E_{dx,dy}$ has a local minimum E_{min} which is not (0, 0)
- E_{min} is our new quality metric

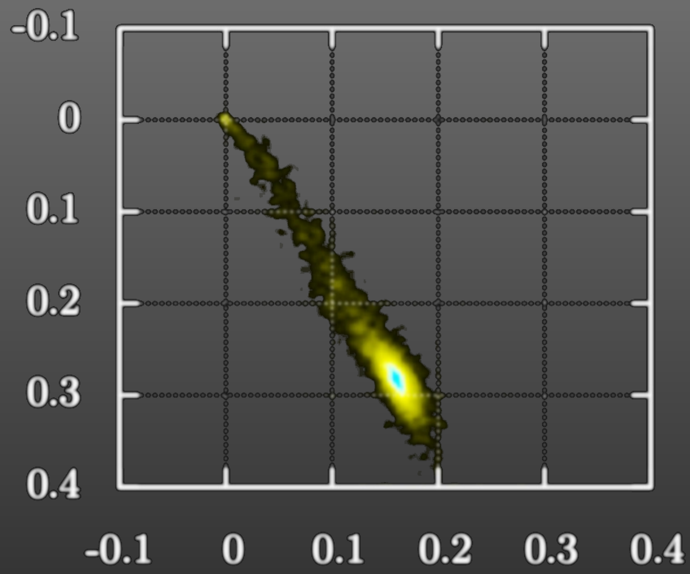
$E_{dx,dy}$ variations for *lena.tga*

- F-S *displacement* for *lena.tga* is (0.28, 0.22):



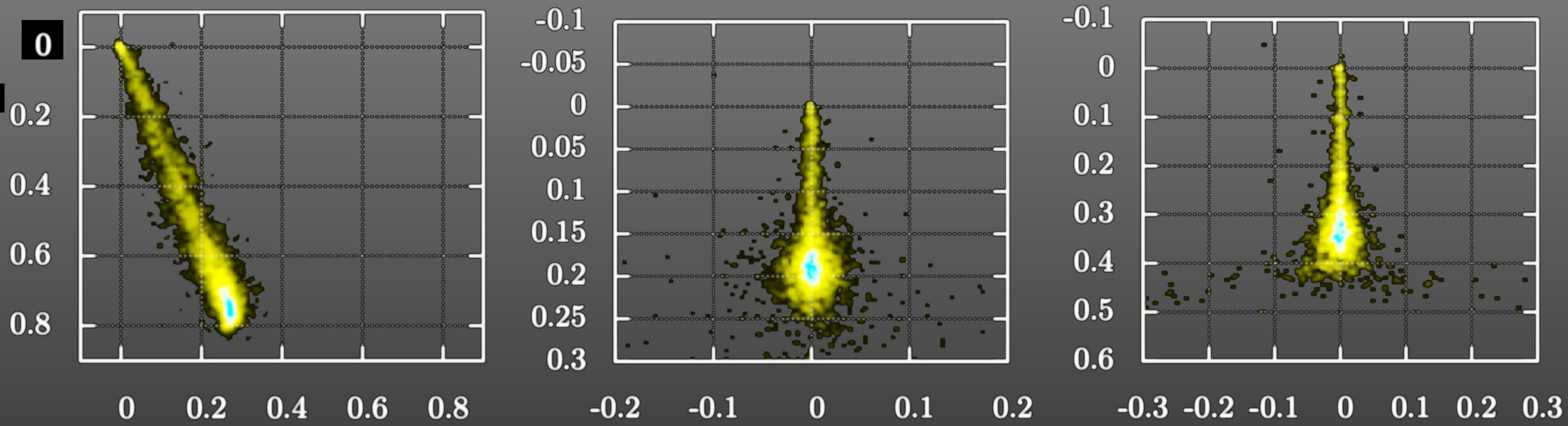
$(dx,dy)_{min}$ variations

- Histogram on a sample of 10,000 images:



- Floyd-Steinberg *displacement* is (0.16, 0.28)
- We introduce $E_{fast} = E_{0.16,0.28}$ which is statistically a better metric than E.

Displacement for other algorithms



- Jarvis-Judice-Ninke: (0.26, 0.76)
- Ostromoukhov: (0.0, 0.19)
- Serpentine optimum: (0.0, 0.34)

Application: improving Floyd-Steinberg

- The idea: find the best Floyd-Steinberg-like diffusion kernel by computing E_{min} for many sample images and diffusion kernels
- We use *CPUShare* (www.cpushare.com) for cheap and secure distributed computing

Results

- Result #1: best kernel is {6, 3, 5, 2}, original Floyd-Steinberg {7, 3, 5, 1} is 2^{nd} best
- Result #2: using E instead of E_{min} elects poor kernels such as {7, 3, 6, 0}
- Result #3: {7, 4, 5, 0} is a much better kernel for serpentine scan than the original Floyd-Steinberg

Future work

- Find a link between $(dx,dy)_{min}$ and the ED kernel
- Optimise other widely-used ED kernels
- Experiment with more complex HVS models